Potential for multi-frequency multi-constellation GNSS augmentation systems in unmanned autonomous systems

M. Felux, M.-S. Circiu, M. Caamano, J. Lee

Our first UAV flight

Our first UAV flight

- Safe?
- Could we trust the positioning?
- Autonomous flying possible?

What do we need for autonomous UAS?

- High accuracy in positioning
- Very high trust in the position solution
- Safe trajectory
- Separation from other traffic

Need for GNSS augmentation

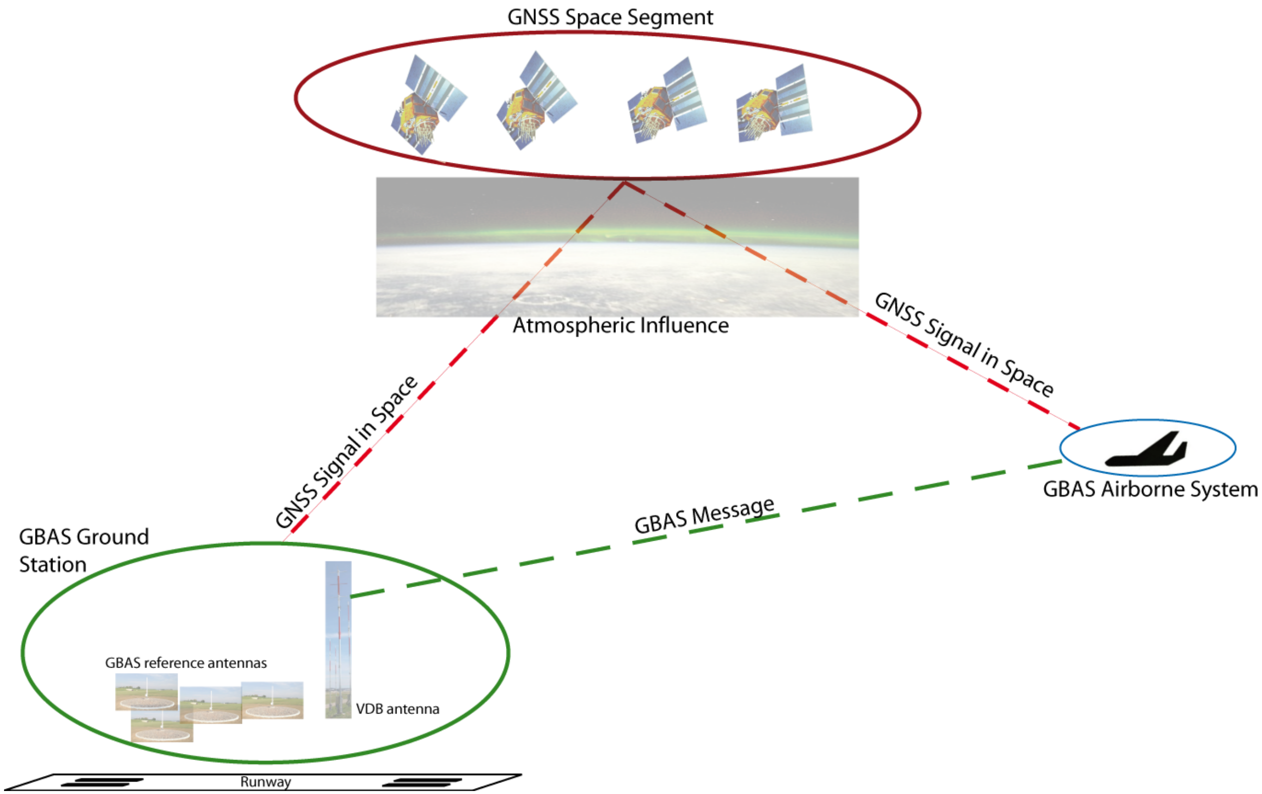
and communication

Outline

- Motivation
- Differential GNSS: GBAS and necessary changes for UAS operations
- Antennas and their effect
- Potential of using a second constellation
- Potential in the new signals on L5
  - Noise and multipath
  - Effect on the smoothing time constant
- Integrity benefits
- Conclusions

GBAS for civil aviation

- The Ground Based Augmentation System (GBAS) provides these services in todays civil aviation

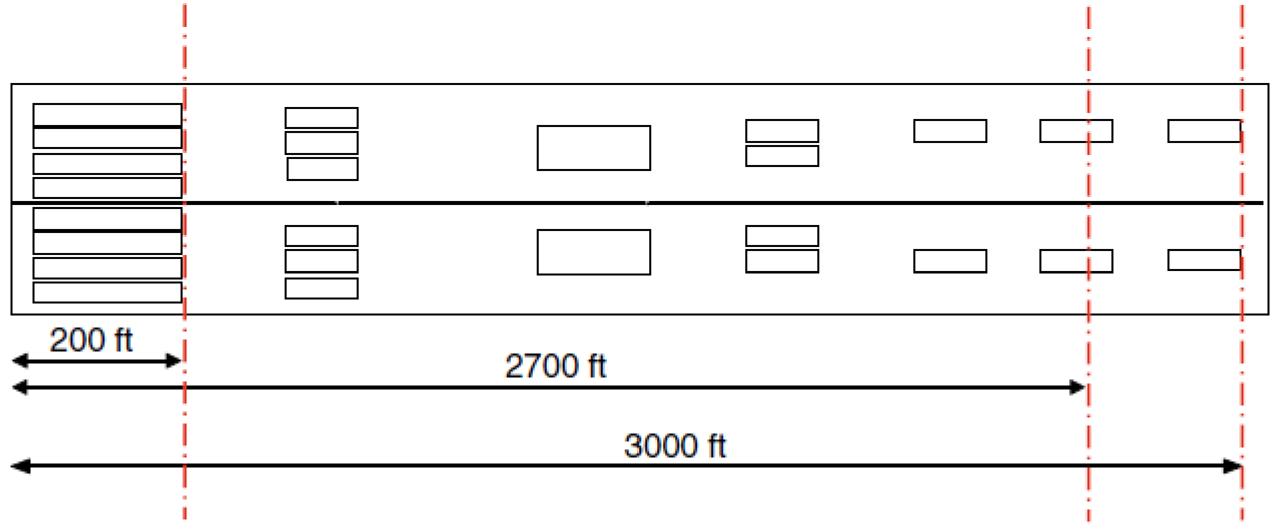


GBAS provides:

- Corrections for GNSS signals
- Good accuracy
- Very high integrity
- Trajectory information

GBAS for civil aviation

- System and requirements specifically designed for landing of aircraft
- Requirements derived from the definition of a safe landing



- Trade-off between integrity and accuracy might be different for UAS ops

GBAS „light“ for UAS applications

GBAS for civil aviation

- Highly tailored to specific application of landing large aircraft
- Special Multipath Limiting Antennas
- Large separation of antennas and very stringent siting requirements
- Typically no influence from ground multipath due to operations at high altitude
- Very constrained VDB data link
- …

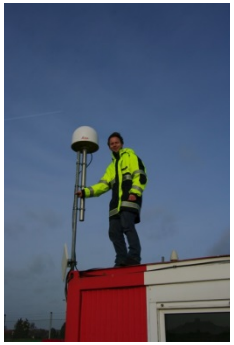
UAS GBAS „light“

- Should support different applications and can be adapted for different uses
- Commercial „off the shelf“ antennas
- Close spacing in non-optimal environment
- Influence of ground multipath very likely due to low operating heights
- Non-constrained data link
- …

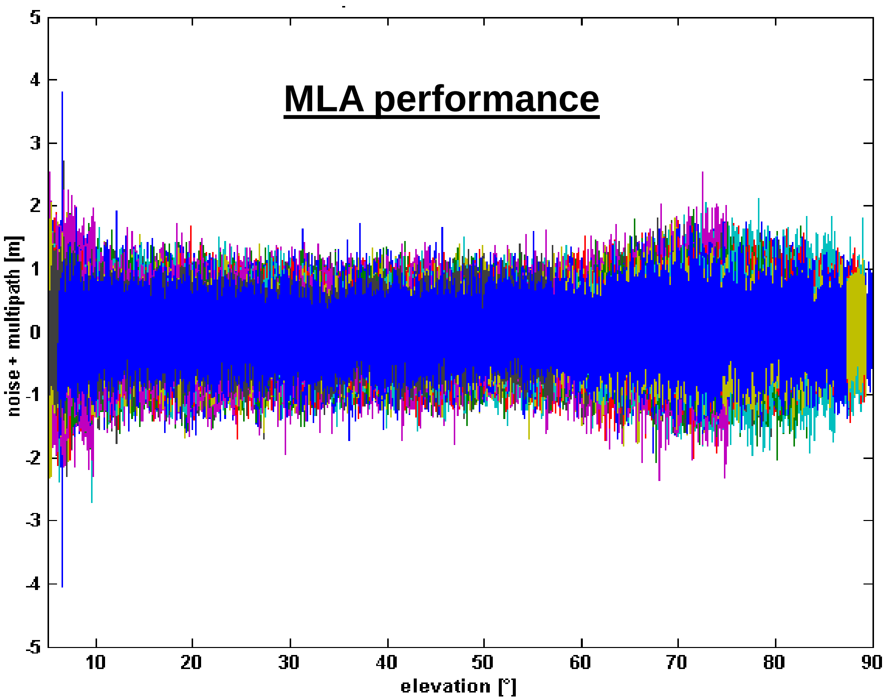
Source: „Local-Area Differential GNSS Architectures Optimized to Support Unmanned Aerial Vehicles (UAVs)“, S. Pullen, P. Enge, J. Lee, Proc. ITM 2013

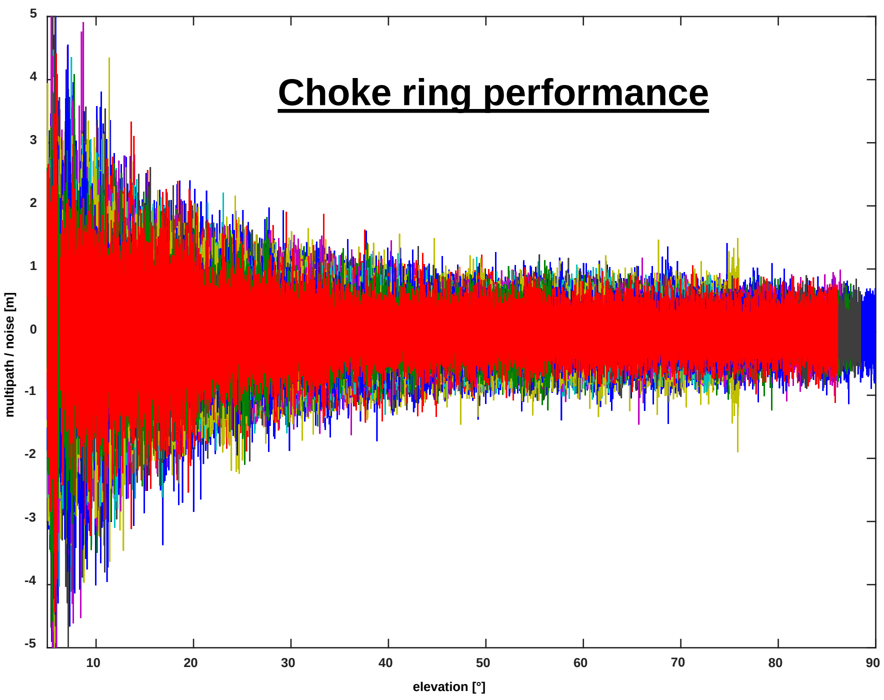
Multi-frequency and multi-constellation GBAS „light“

- DLR‘s GBAS test bed is using chokering antennas



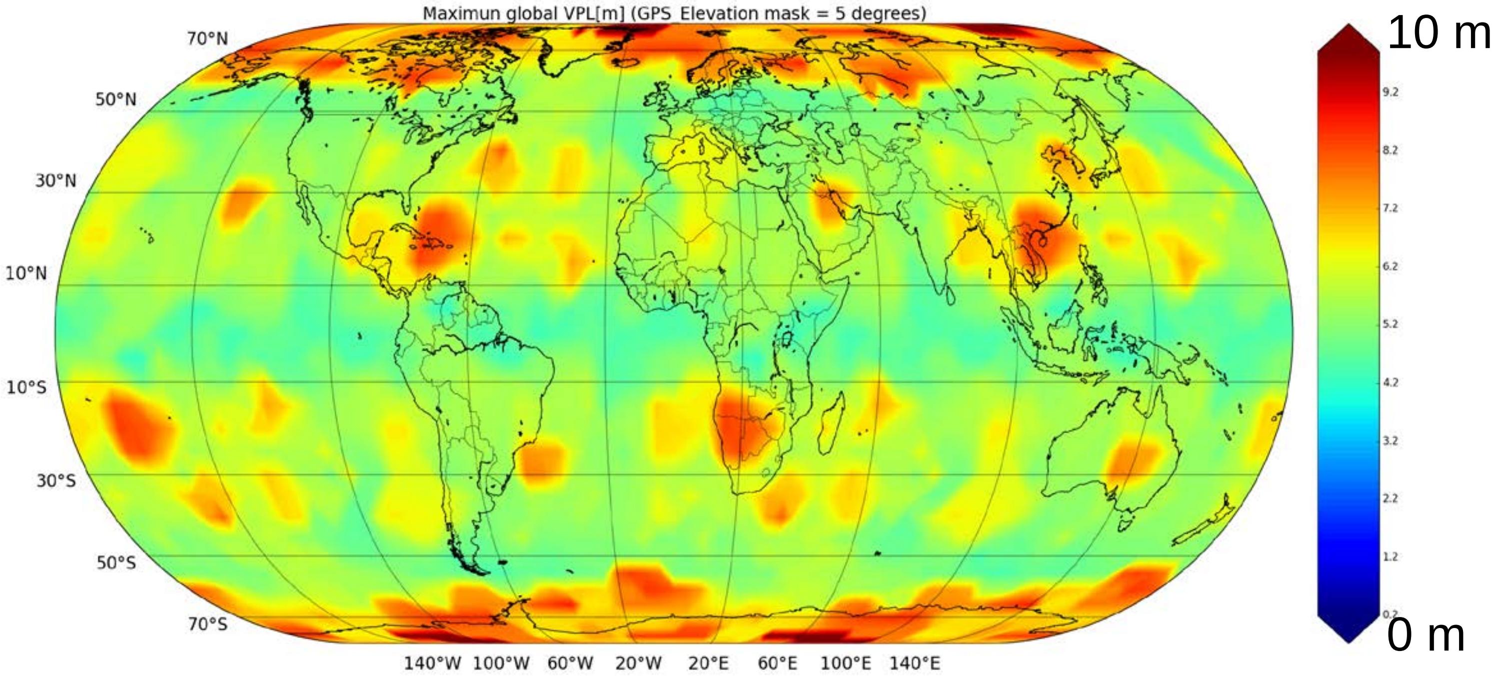
GBAS MLA vs. commercial choke-ring antenna



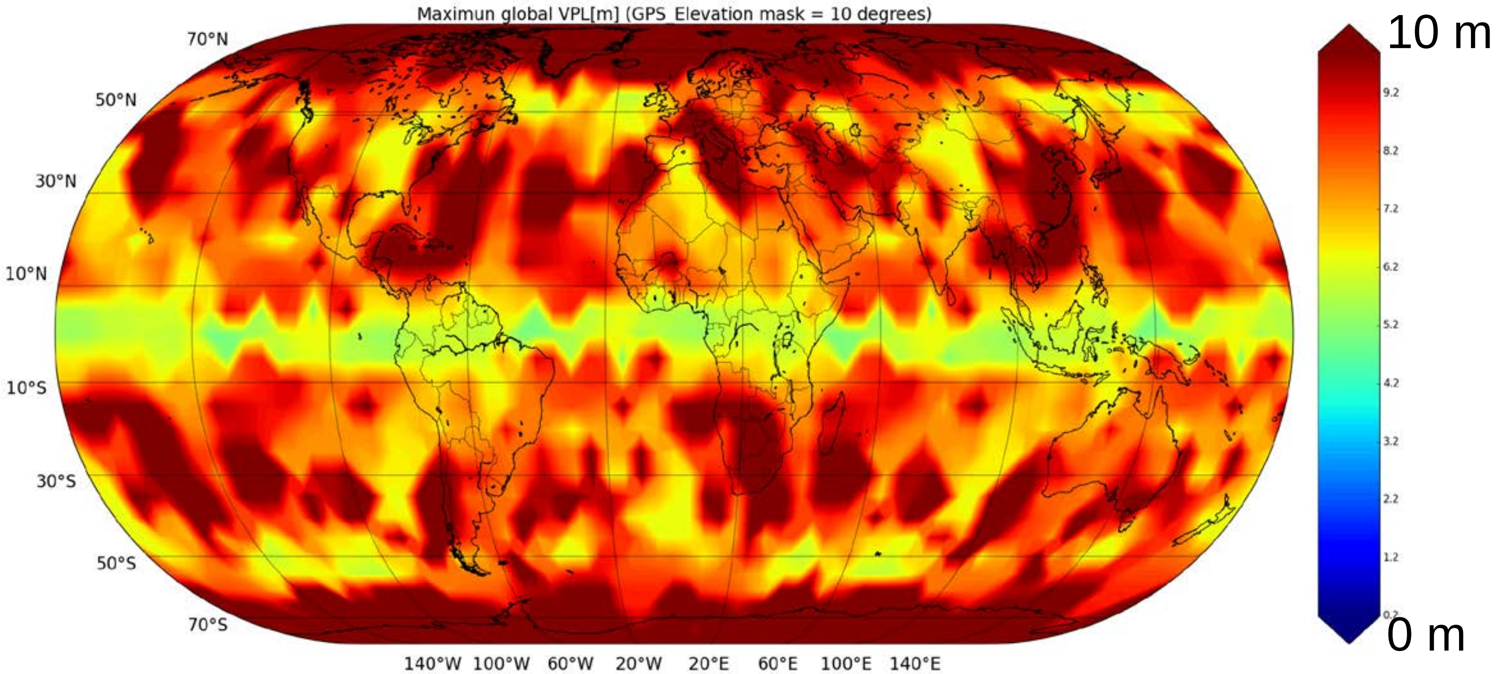


- Similar noise/multipath performance above 20°
- Possibility to raise elevation mask?

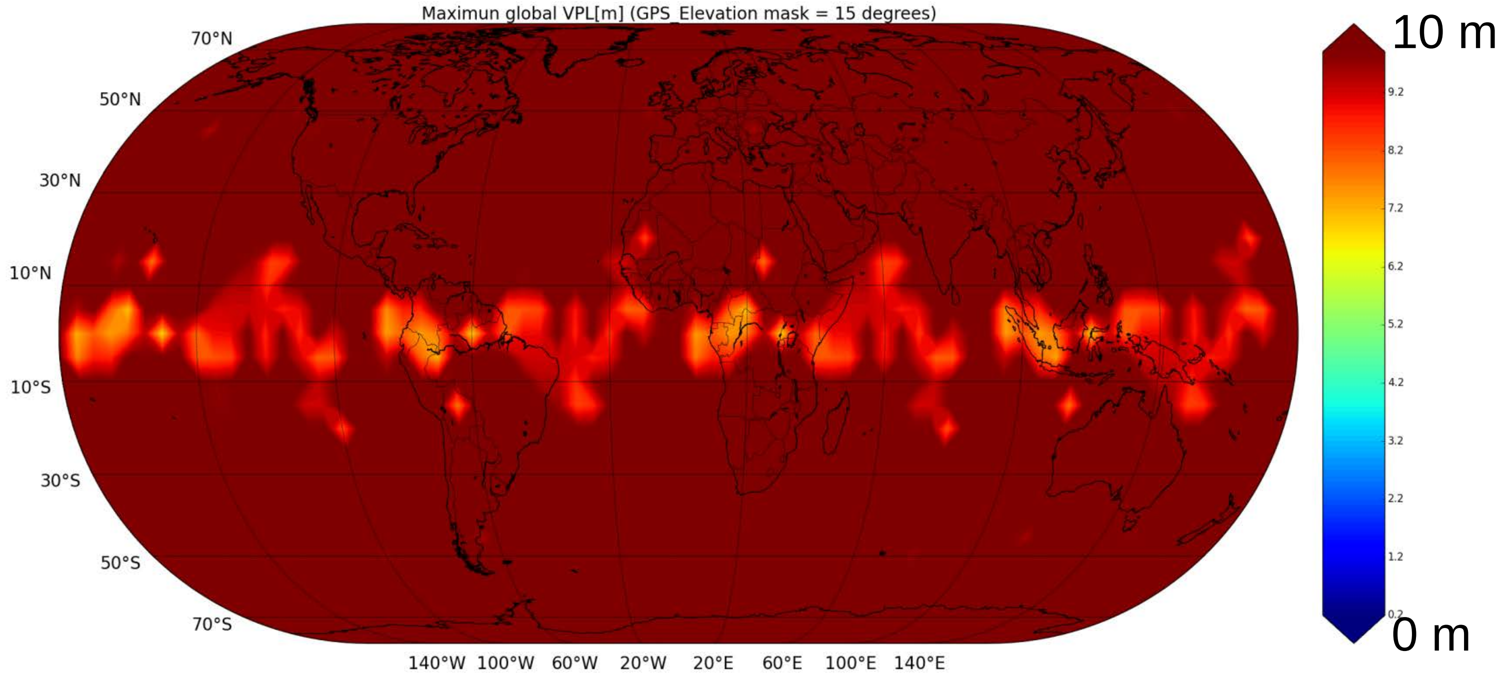
Multi-constellation benefits
5° elevation mask – single constellation



Multi-constellation benefits
10° elevation mask – single constellation

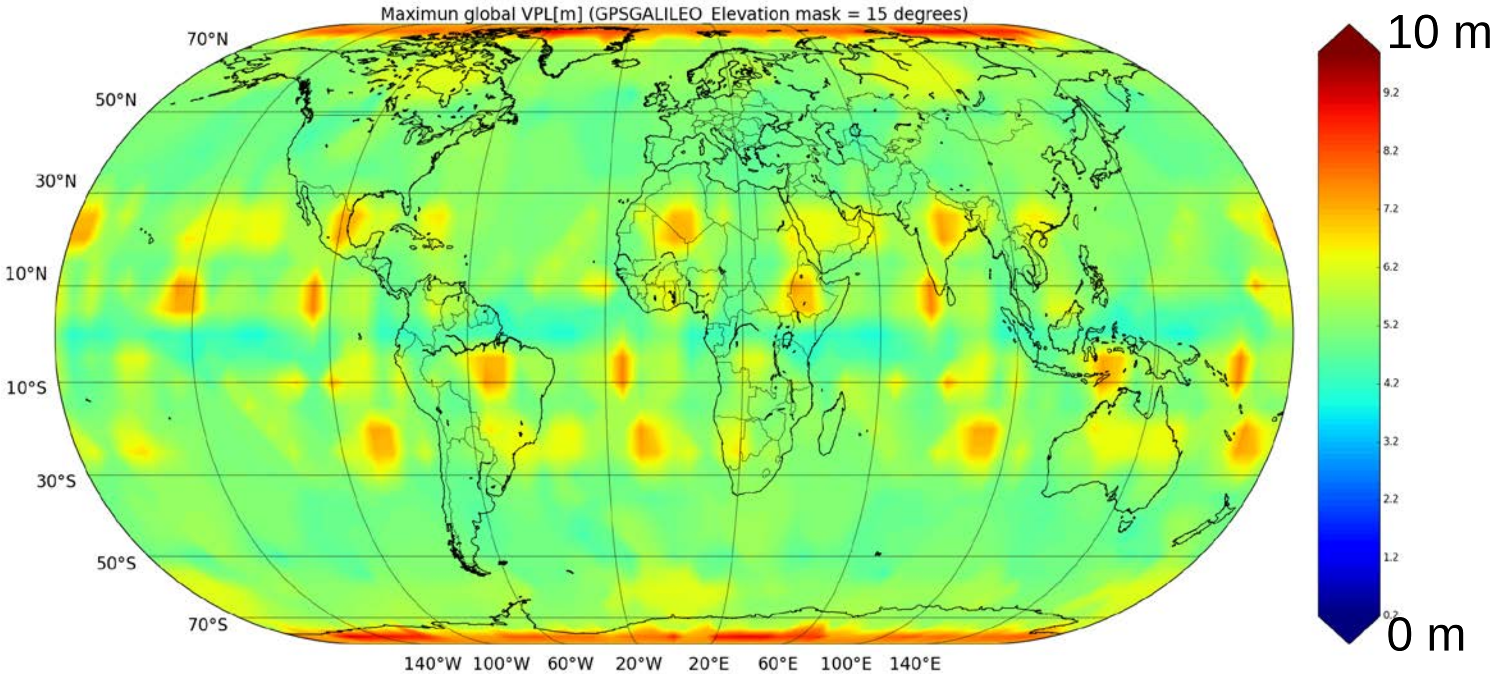


Multi-constellation benefits
15° elevation mask – single constellation

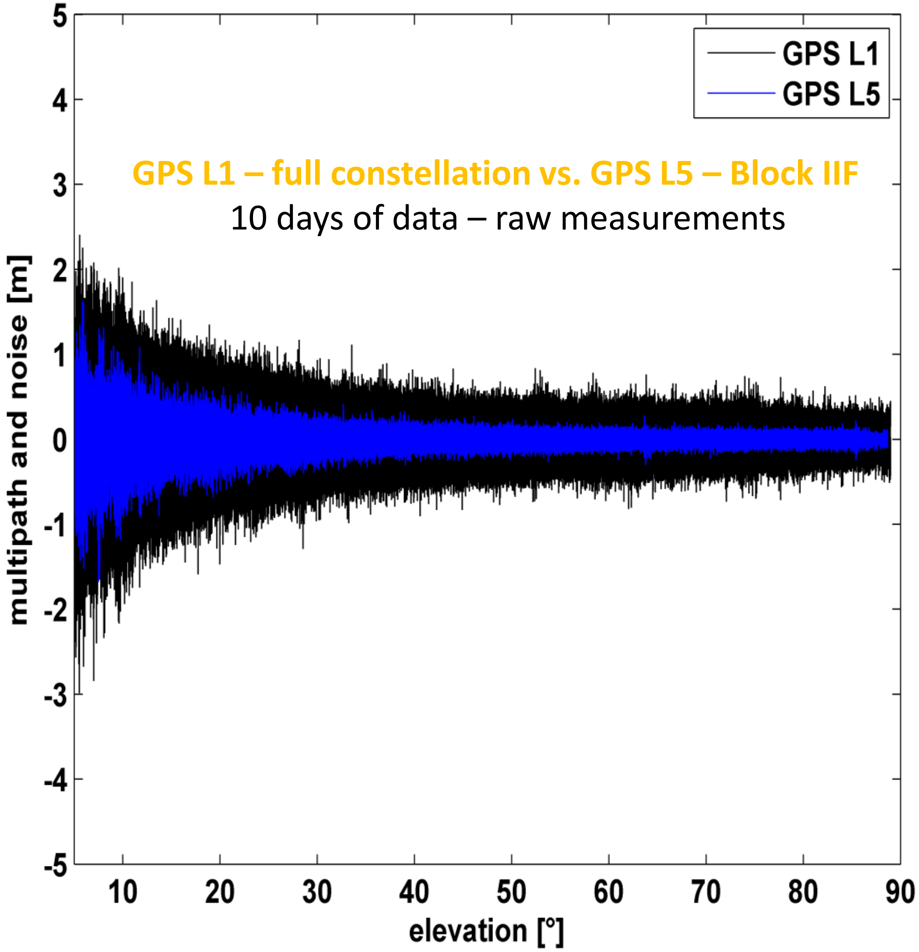


Multi-constellation benefits
15° elevation mask – dual constellation

- Increased number of satellites provides possibility to raise elevation mask

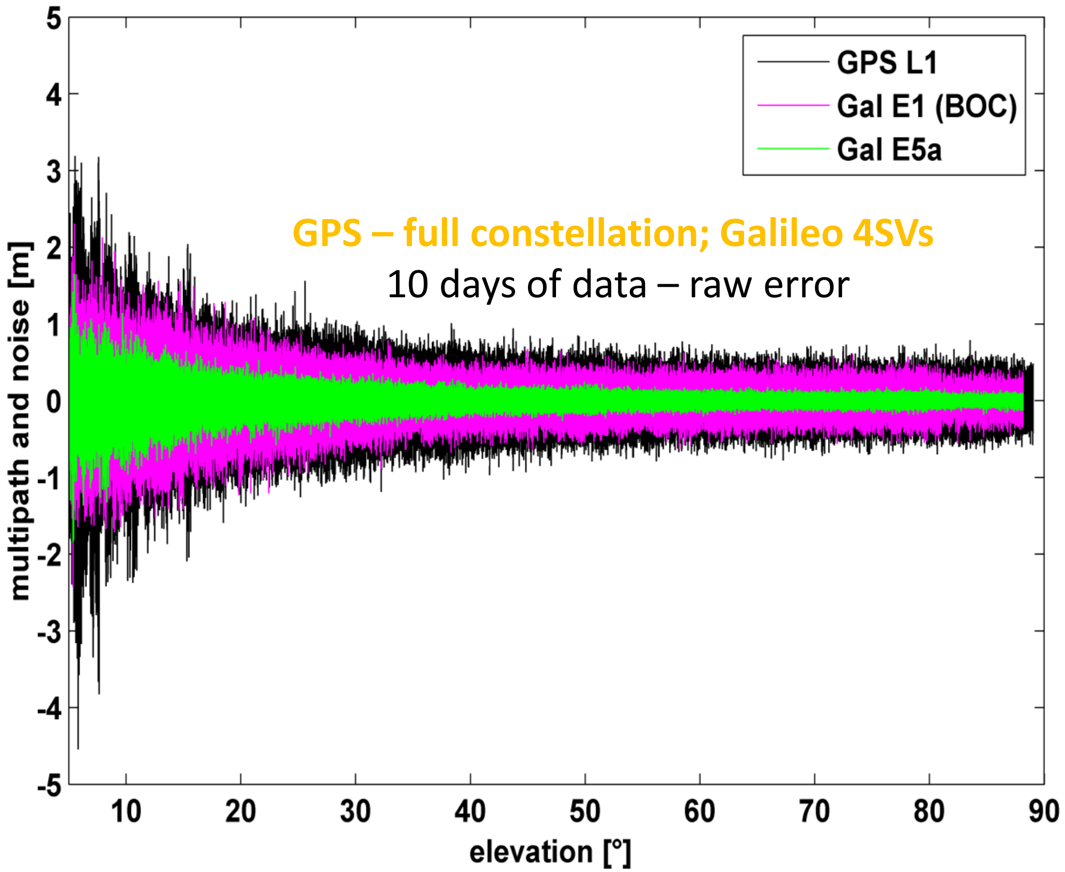


Multi-frequency benefits



- GPS L5 shows an improvement in terms of noise and multipath
    - BPSK(10) signal
    - Higher chipping rate
    - Higher transmitted power

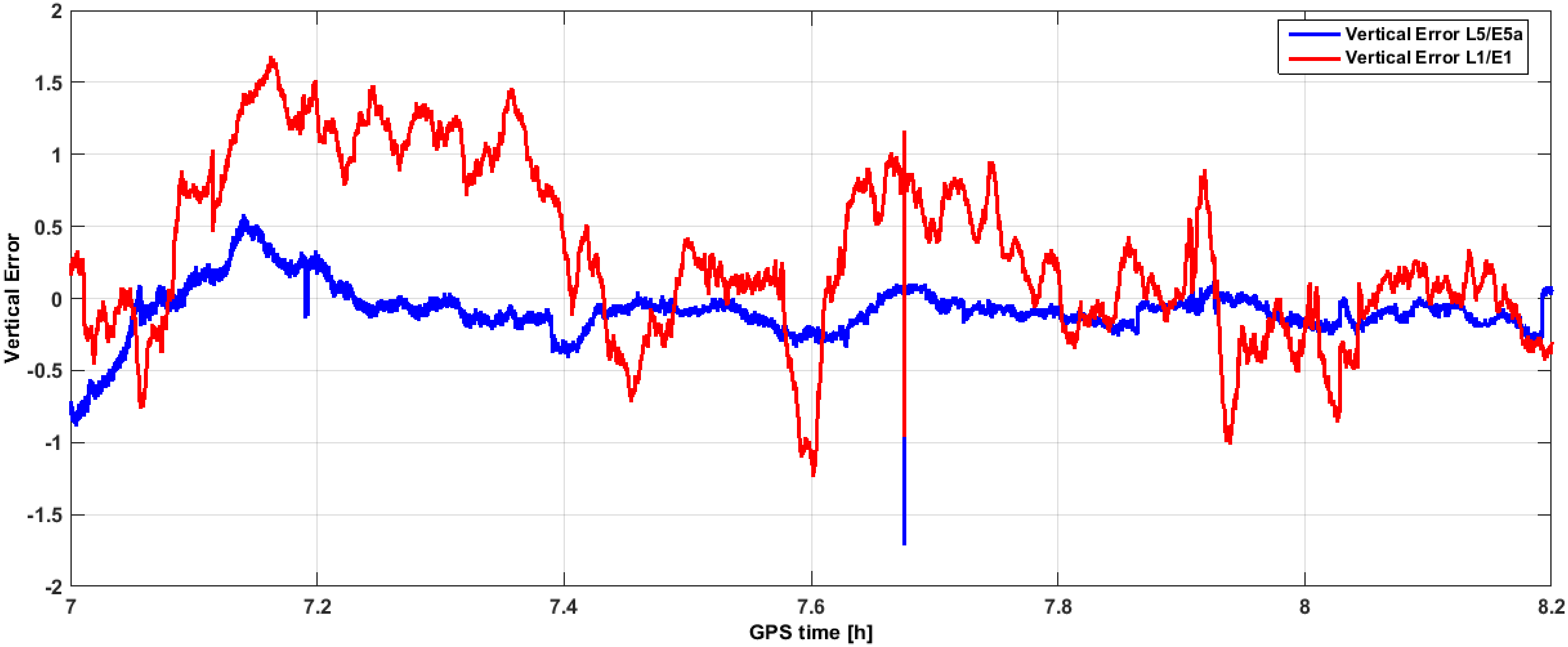
Multi-frequency benefits



- Multipath and noise on Galileo E1 is lower than on GPS L1, especially at low elevation
    - BOC(1,1) modulation
    - Wider transmission bandwidth
- Galileo E5a shows lower multipath and noise than Galileo E1
    - BPSK(10) signal
    - Higher chip rate
    - Higher signal power

Accuracy improvements

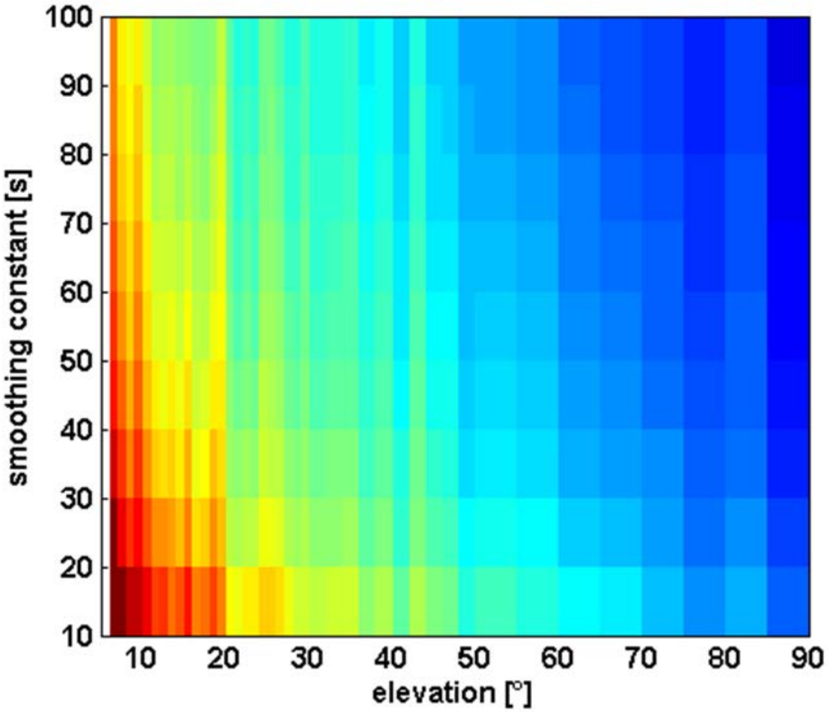
- Lower position errors with L5



Results from DFDC GBAS flight tests

Multi-frequency benefits

GPS L1 – BPSK(1) signal



GPS L5 – BPSK(10) signal

- Sensitive to the smoothing constant for elevations below 60°
- Low sensitivity to the smoothing constant for almost all elevations

- **Sensitivity (if any) grows as elevation angle decreases**

Integrity benefits. Protection levels

The position errors have to be bounded -> modeling of the total standard deviation of each differentially corrected pseudo-range measurement

$$VPL_{H0} = K_{ffmd}\sqrt{\sum_{i=1}^{n} S_{apr_{vert}}^{2}\ \sigma_i^2} \qquad LPL_{H0} = K_{ffmd}\sqrt{\sum_{i=1}^{n} S_{apr_{lat}}^{2}\ \sigma_i^2}$$

$$\sigma_i = std\ of\ the\ residual\ GBAS\ error\ overbound$$

$$\boldsymbol{\sigma_i^2} = \boldsymbol{\sigma_{pr\_gnd}^2} + \sigma_{tropo}^2 + \sigma_{iono}^2 + \boldsymbol{\sigma_{air}^2}$$

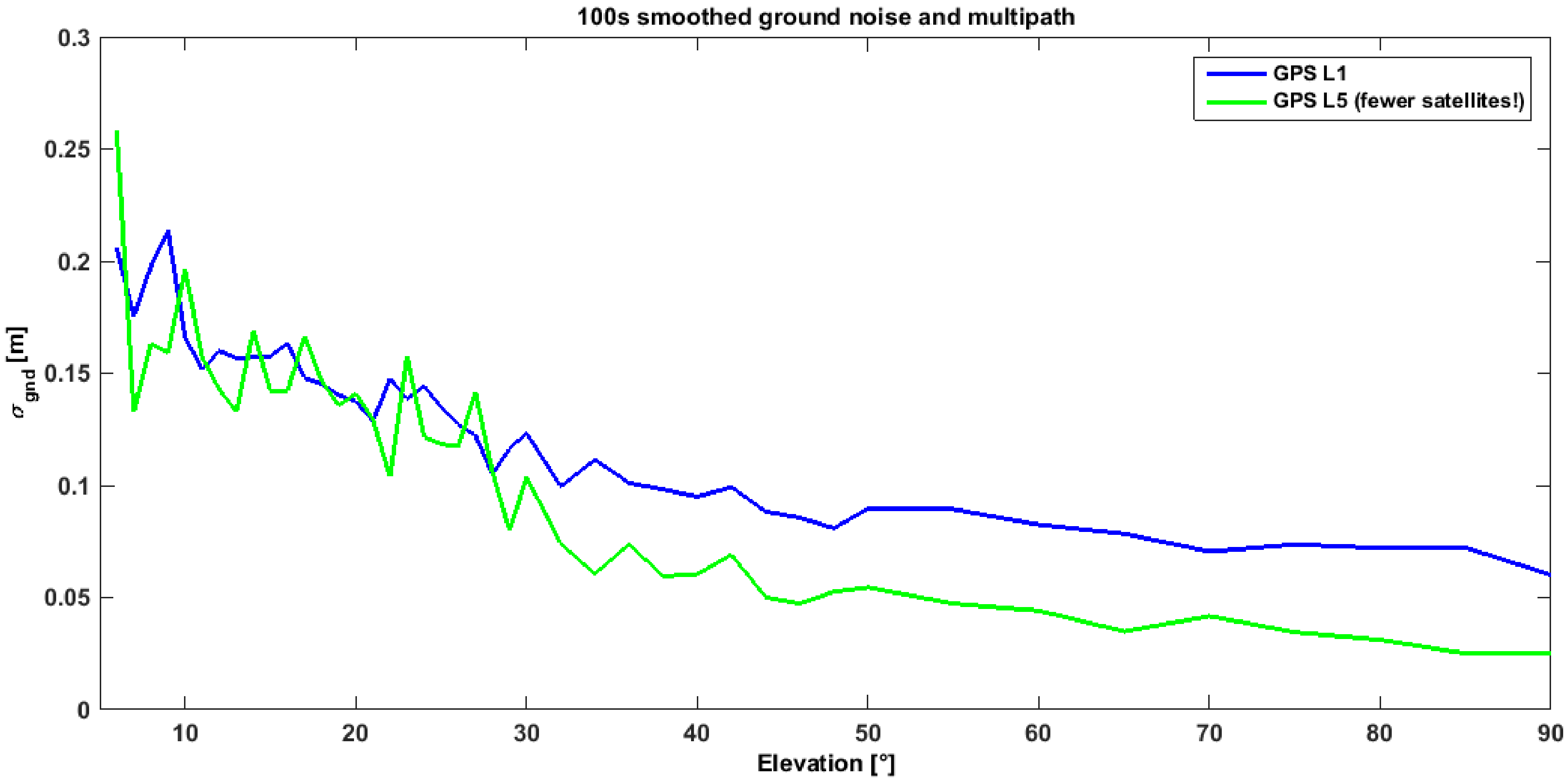
uncertainty introduced by the ground multipath and noise (Computed based on measurements)

residual tropospheric error (Model)

residual ionospheric error (Model)

uncertainty introduced by the airborne multipath and noise (Conservative models)

Evaluation of σ_{pr_gnd} for GPS L1 and L5



- The difference shrinks after carrier smoothing, but L5 performance is still better, especially at high elevations

Results of the Airborne Multipath on Airbus A320

Receiver

Bandwidth 23 MHz

Correlator spacing

0.1 chips for L1

1 chip for L5/E5a

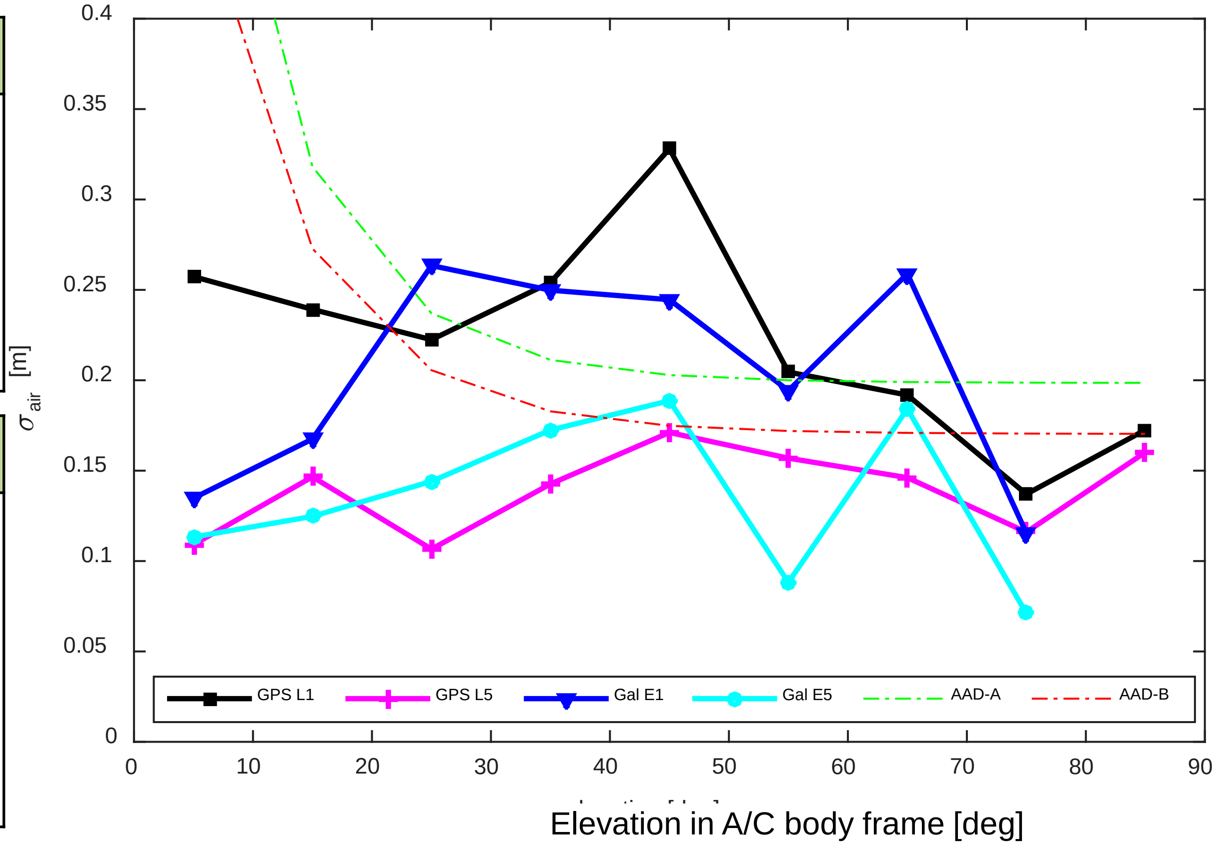
Data

14 flights, 30 hours

9 GPS Block IIF satellites

3 Galileo healthy

100 seconds smoothing constant

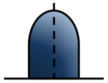


Results

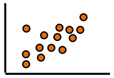
- Improved performance of GPS L5 and Galileo E5a signals compared to GPS L1 - higher chipping rate than L1 and higher transmitted power

UAV Hardware configuration for data collection

Receiver



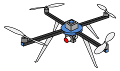
Bandwidth 15 MHz



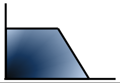
Correlator spacing
0.1 chips for L1/E1

Data

10 flights, 30 hours



20 m hovering
(0 m,10m also tested)

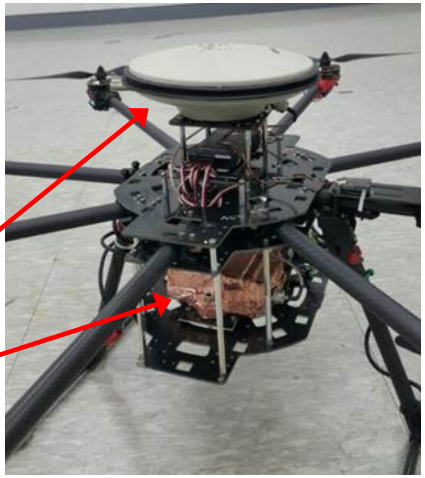


100 seconds smoothing constant

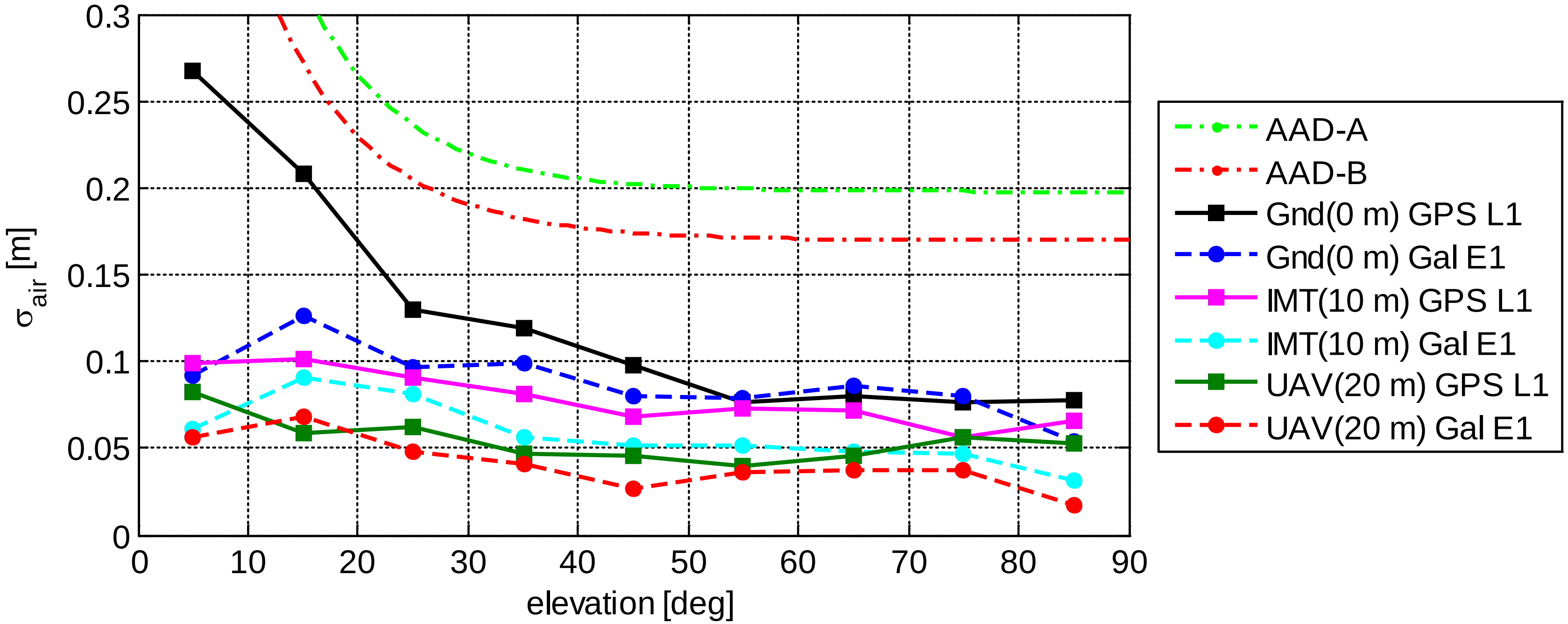
Octo-rotor
- 1,350 mm diameter
- 450 mm height

Novatel GPS-703-GGG antenna

Novatel FlexPak-6 receiver



Impact of the ground reflections

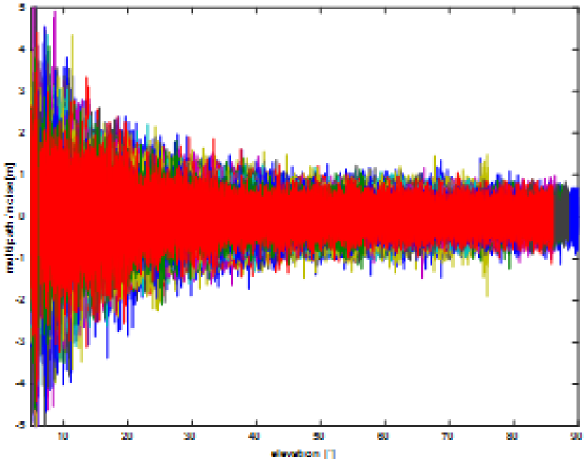


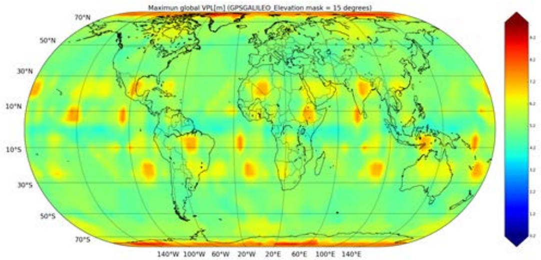
Results

- Ground reflections of GPS L1 and Galileo E1 differ depending on the altitude of antenna
- Galileo E1 signal show better performance than GPS L1 signal specially at low elevation when measurements are collected from UAV on the ground(0 m) at low elevation – better rejection of long-range multipath
- From UAV around 20 m, Galileo E1 performance is close to that of GPS L1

Conclusions

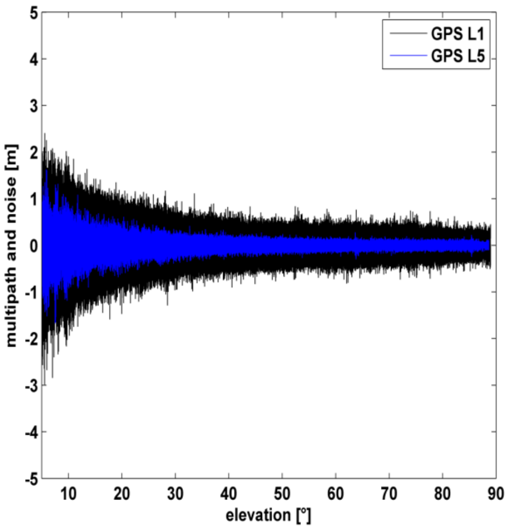
- UAS need high accuracy and high integrity
- Local augmentation will use different hardware
- Multi-constellation augmentation allows for significant elevation masking

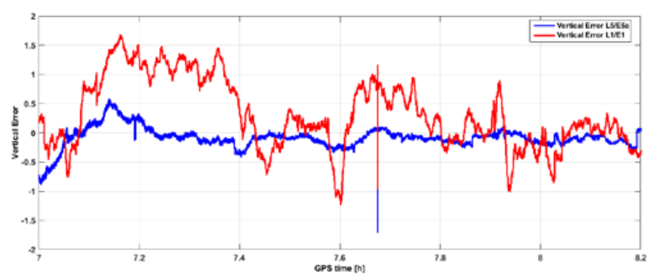




Conclusions

- New signals provide lower noise
  - Better accuracy
  - Smaller protection levels for integrity benefits





Thank you very much for your invitation!